Can J Anesth/J Can Anesth (2013) 60:38–43
DOI 10.1007/s12630-012-9814-5

REPORTS OF ORIGINAL INVESTIGATIONS

The scavenging of volatile anesthetic agents in the cardiovascular intensive care unit environment: a technical report

La récupération des agents anesthésiques volatils dans l'environnement de l'unité des soins intensifs cardiovasculaires: un rapport technique

Thomas Pickworth, MBBS · Angela Jerath, MBBS · Rita DeVine, RRT · Nazmin Kherani, RRT · Marcin Wąsowicz, MD, PhD

Received: 20 June 2012 / Accepted: 16 October 2012 / Published online: 7 November 2012

Abstract

Purpose *The use of volatile-based sedation within critical care environments has been limited by difficulties of drug administration and safety concerns over environment pollution and staff exposure in an intensive care unit (ICU) with no scavenging. The aim of this study was to develop a simple scavenging system to be used with the Anesthesia Conserving Device (AnaConDa®) and to determine whether or not ambient concentrations of residual anesthetic are within current acceptable limits.*

Technical features *The scavenging system consists of two Deltasorb® canisters attached to the ICU ventilator in series. AnaConDa is a miniature vaporizer designed to provide volatile-based sedation within an ICU. The first ten patients recruited into a larger randomized trial assessing outcomes after elective coronary graft bypass surgery were sedated within the cardiac ICU using either isoflurane or sevoflurane. Sedation was guided by the Sedation Agitation Scale, resulting in an end-tidal minimum anesthetic concentration of volatile agent ranging from 0.1-0.3. At one hour post ICU admission, infrared photometric analysis was used to assess environmental contamination at four points along the ventilator circuit and scavenging system and around the patient's head. All measurements taken within the patient's room were below 1 part per million, which satisfies criteria for occupational exposure.*

Conclusions *This study shows that volatile agents can be administered safely within critical care settings using a simple scavenging system. Our scavenging system used in conjunction with the AnaConDa device reduced the concentration of environmental contamination to a level that is acceptable to Canadian standards and standards in most Western countries and thus conforms to international safety standards. The related clinical trial was registered at www.clinicaltrials.gov (NCT01151254).*

Résumé

Objectif *L'utilisation de sédation aux agents volatils dans les environnements de soins critiques a été limitée par les difficultés d'administration du médicament et des inquiétudes quant à la sécurité en matière de pollution de l'environnement et d'exposition du personnel dans une unité de soins intensifs (USI) sans système de récupération. L'objectif de cette étude était de mettre au point un système de récupération simple qui pourrait être utilisé avec le Dispositif de conservation de l'anesthésie (AnaConDa®) et de déterminer si oui ou non les concentrations ambiantes*

Author contributions *Thomas Pickworth* wrote the first version of the manuscript and participated in all subsequent revisions. *Thomas Pickworth*, *Angela Jerath, Nazmin Kherani,* and *Marcin Wasowicz* participated in the measurements of volatile concentration. *Angela Jerath* and *Marcin Wasowicz* participated in the final revisions of the manuscript. *Rita Devine* designed a scavenging system. *Marcin Wąsowicz* participated in all revisions of the manuscript, designed the study protocol, and secured funds to conduct the study.

T. Pickworth, MBBS · A. Jerath, MBBS · M. Wąsowicz, MD, PhD (✉)
Department of Anesthesia and Pain Management,
Toronto General Hospital/University Health Network,
200 Elizabeth Street, Toronto, ON M5G 2C4, Canada
e-mail: marcin.wasowicz@uhn.ca

A. Jerath, MBBS · M. Wąsowicz, MD, PhD
Department of Anesthesia, Faculty of Medicine,
University of Toronto, Toronto, ON, Canada

R. DeVine, RRT · N. Kherani, RRT
Department of Respiratory Therapy, Toronto General Hospital/
University Health Network, Toronto, ON, Canada

d'anesthésique résiduel se situaient dans des limites actuellement acceptables.

Éléments techniques *Le système de récupération est composé de deux réservoirs Deltasorb® attachés en série au ventilateur de l'USI. L'AnaConDa est un vaporisateur miniature conçu pour fournir une sédation à base d'agents volatils dans une USI. Les dix premiers patients recrutés dans une étude randomisée de plus grande envergure évaluant les devenirs après une chirurgie de pontage aorto-coronarien non urgente ont été mis sous sédation dans l'USI cardiaque avec de l'isoflurane ou du sévoflurane. La sédation a été réalisée selon l'Échelle d'agitation pendant la sédation, avec pour résultat une concentration télé-expiratoire minimum d'agent volatil se situant entre 0,1 et 0,3. Une heure après l'admission à l'USI, une analyse photométrique infrarouge a été réalisée pour évaluer la contamination environnementale à quatre endroits le long du circuit du ventilateur et du système de récupération ainsi qu'autour de la tête du patient. Toutes les mesures prises dans la chambre du patient étaient au dessous de 1 partie par million (ppm), ce qui est conforme aux critères d'exposition professionnelle.*

Conclusion *Cette étude démontre que les agents volatils peuvent être administrés de façon sécuritaire dans un cadre de soins critiques grâce à un simple système de récupération. Notre système de récupération, utilisé en conjonction avec le dispositif AnaConDa, a réduit la concentration de contamination environnementale à un niveau acceptable selon les normes canadiennes et les normes de la plupart des pays occidentaux; ainsi, la concentration est conforme aux normes internationales de sécurité. L'étude clinique liée a été enregistrée au www.clinicaltrials.gov (NCT01151254).*

Volatile anesthetic agents have been used in the intensive care unit (ICU) for over 30 years.[1,2] Their application as sedatives has been limited to patients suffering from severe reactive airway disease or status epilepticus.[3-8] There has been a renewed interest in the use of volatile-based sedation within critical care environments given the potential benefits of shorter ventilation time, better pulmonary ventilation/perfusion matching, an improved sedation profile with precise control of dosing, organ protective properties (pre-and post-conditioning), and minimal systemic metabolism with lack of drug accumulation and sedative effects after administration is discontinued. Nevertheless, the use of volatile sedation has been practically limited by the requirement of a bulky expensive anesthetic machine, appropriate scavenging, and the need for the constant presence of an anesthesiologist.

Many of these issues have been overcome with the introduction of the Anesthetic Conserving Device (AnaConDa®, Sedana Medica, Sweden). This highly efficient lightweight and portable mini-vaporizer is placed between the breathing circuit and endotracheal tube and can be used with any type of ICU ventilator. The device is simple to use, and sedation can be easily monitored and titrated by the nursing staff.[1] However, use of volatile agents requires scavenging to reduce ambient room contamination and staff exposure to trace amounts of volatile anesthetics. Scavenging systems within critical care environments are uncommon, which has been a major barrier to the use of these agents in this setting. Current Ontario Ministry of Labour guidelines based on the Occupational Health and Safety Act state that levels of halogenated volatile agents in the working environment should not exceed 2 parts per million (ppm).[9]

The aim of this study was to assess the efficacy of a simple scavenging system consisting of two Deltasorb® canisters attached in series to an ICU ventilator and used in conjunction with the AnaConDa device. Additionally, we assessed the concentration of postoperatively administered volatile anesthetic agents to which cardiac surgical patients and the local environment were exposed.

Methods

We obtained approval for our study from Health Canada and from the Research Ethics Board of the University Health Network after performing an initial safety study to meet their requirements. We then conducted a large randomized controlled trial comparing the use of propofol *vs* volatile-based anesthesia for postoperative sedation in cardiac surgical patients. This study was registered as a clinical trial (NCT01151254) and the results have been recently reported.[10,11] In order to undertake this large randomized controlled trial, we were required to perform an initial safety study to meet the requirements for Health Canada and Research Ethics Board of University Health Network. All patients recruited within this study provided written informed consent. Patients scheduled for elective aortocoronary bypass grafting with grade 1 or 2 left ventricular systolic function were included in the study. Patients were excluded if they had a history of malignant hyperthermia, propofol infusion syndrome, severe kidney or liver dysfunction, or if they required sedation in excess of 14 hr or chest re-exploration. To assess the safety of volatile-based sedation, the first ten patients randomized to the volatile group were selected to participate within this sub-study. Reporting the data from our initial ten patients did not comprise the overall blinding of procedures. These patients received intraoperative volatile anesthesia and postoperative sedation within the cardiovascular ICU using the same agent with the AnaConDa device. Either sevoflurane or isoflurane was chosen at the discretion of the attending anesthesiologist (Table 1).

The AnaConDa device is a combined miniature vaporizer, microbial filter, and heat-moisture exchanger (Fig. 1a and 1b). The volatile agent is infused into the device by a syringe pump at a rate of 0.5-30 $mL \cdot hr^{-1}$ depending on the needs and requirements of the patient. The volatile agent evaporates within the device, which is placed between the endotracheal tube and the Y-piece of the breathing circuit (Fig. 2). The expired gas is resorbed and recycled on a carbon reflection layer. The overall efficiency of the AnaConDa device exceeds 90%, which accounts for the small infusion volumes required.[2] The device has a dead space of 100 mL but a large internal surface area (Fig. 1b). This facilitates both rapid volatile vaporization and changes in concentration in response to the infusion rate which allow for quick changes in the depth of sedation. AnaConDa has an additional sampling port that allows breath-by-breath measurement of end-tidal concentration of volatile agents and expired gases. In our study, we used an A3 Anesthesia Gas Monitor® (Datex-Ohmeda, Madison, WI, USA). Postoperatively, patients were sedated to an end-tidal concentration of 0.1-0.3 minimum anesthetic concentration (MAC), aiming for a sedation score of 2-3 using the Sedation Agitation Scale.[12] However, anesthetic doses of 0.6 MAC where used if necessary to manage inadequate sedation.

The scavenging system developed within our institution consists of two Deltasorb canisters (Blue-Zone, Concord, ON, Canada) assembled in series to an ICU ventilator (Nellcor Puritan Bennett 760, Vancouver, BC, Canada) (Fig. 3a). The proximal end is attached to the expiratory port of the ventilator, and the distal end is attached to the central scavenging port. The reservoir bag was installed after the second Deltasorb canister in order to avoid overpressurizing the system or applying excessive vacuum (Fig 3B). Each Deltasorb canister consists of a hydrophobic crystalline matrix of silica zeolite (Deltazite®).[13,14] Deltazite adsorbent is an inert non-reactive inorganic high-silica-based filter with a unique uniform pore lattice structure that selectively captures volatile agents from the gas mixture passing through the Deltasorb canister. This compound acts as a molecular sieve and selectively adsorbs isoflurane, sevoflurane, and desflurane. The Deltasorb canister is a portable non-pressurized non-hazardous self-contained SS 316 cylinder with individually identified serial numbers for tracking and traceability. It is a passive device that contains proprietary Deltazite adsorbent. It is known to adsorb selectively by isolating diluted halogenated volatile inhalation anesthetics from anesthesia machine scavenging systems.[13,14] Deltazite compound allows desorption of volatile agents that could potentially be recycled. After its use, the Deltasorb canister with its exhausted proprietary adsorbent matrix is exchanged by Blue-Zone Technologies and subsequently regenerated by their proprietary process where halogenated hydrocarbons are simultaneously extracted from the Deltazite.

A multigas infrared vapour analyzer (InfraRan Specific Vapor Analyzer, Wilkins Enterprise Inc., Worcester, MA, USA) was used to measure volatile concentrations within the scavenging system and in the patient's room. The analyzer uses an infrared calibrated photometric beam to measure volatile concentrations in real time with values displayed in ppm. The operator determines which gas is to be analyzed and the machine is calibrated prior to performing each measurement. One hour after admission to the cardiovascular ICU, the concentration of anesthetic gas was measured using the analyzer at four locations; the expiratory limb of the ventilator, post 1st Deltasorb, post 2nd Deltasorb, and around the patient's head (Fig. 2). Gas concentrations are recorded as ppm, and the average concentration at each location is reported as mean (standard deviation). In addition, we recorded any technical difficulties of the scavenging system or AnaConDa device until the patient's trachea was extubated.

Table 1 Concentration of volatile agents measured in parts per million (ppm) at four points within the breathing circuit and patient room

Patient Number	Volatile Used	Expiratory Limb	Post 1st Deltasorb	Post 2nd Deltasorb	Room atmosphere
1	Sevoflurane	32	10	8	0
2	Isoflurane	0	0	0	0
3	Isoflurane	5	2	1	0
4	Sevoflurane	18	8	4	1
5	Isoflurane	1	1	1	0
6	Sevoflurane	1	0	0	0
7	Sevoflurane	10	1	2	0
8	Isoflurane	4	4	1	1
9	Sevoflurane	1	1	1	1
10	Sevoflurane	10	5	3	1
Mean (SD)		8.2 (10.1)	3.2 (3.5)	2.1 (2.4)	0.4 (0.5)

SD = standard deviation; ppm = parts per million

Results

Six hundred eighty-eight patients were assessed for study eligibility and 176 patients gave written informed consent. Seventy-nine patients received volatile-based anesthesia and sedation. The first ten patients from this group were included within this sub-study. Recruitment was performed over two years commencing from September 2009 to August 2011. The concentration of volatile anesthetic measured at the four points is presented in Table 1. The mean concentrations at the expiratory limb, post 1st Deltasorb, post 2nd Deltasorb, and around the patient's head were 8.2 ppm, 3.2 ppm, 2.1 ppm, and 0.4 ppm, respectively. No readings from within the patient's room exceeded 1 ppm. We did not encounter any technical problems with the device or scavenging system during the study period.

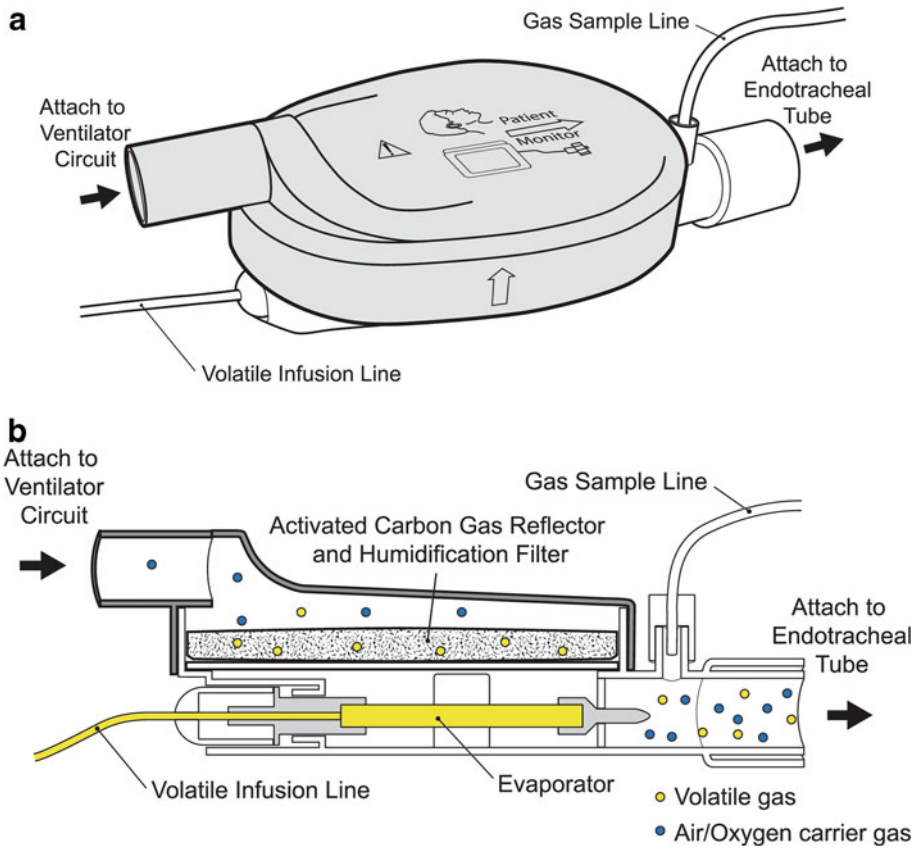

Fig. 1 (a) AnaConDa® is a lightweight device placed between the ventilator circuit Y-piece and the endotracheal tube. The volatile agent is infused into the device via a syringe drive. A gas sampling port allows for continuous end-tidal agent and gas monitoring. (b) The volatile agent is evaporated within the device. The activated carbon layer recycles expired gas, which accounts for its high efficiency. AnaConDa possesses an in-built humidification/filter layer thus requiring no external device within the ventilator circuit. Illustrations are courtesy of J. Crossingham

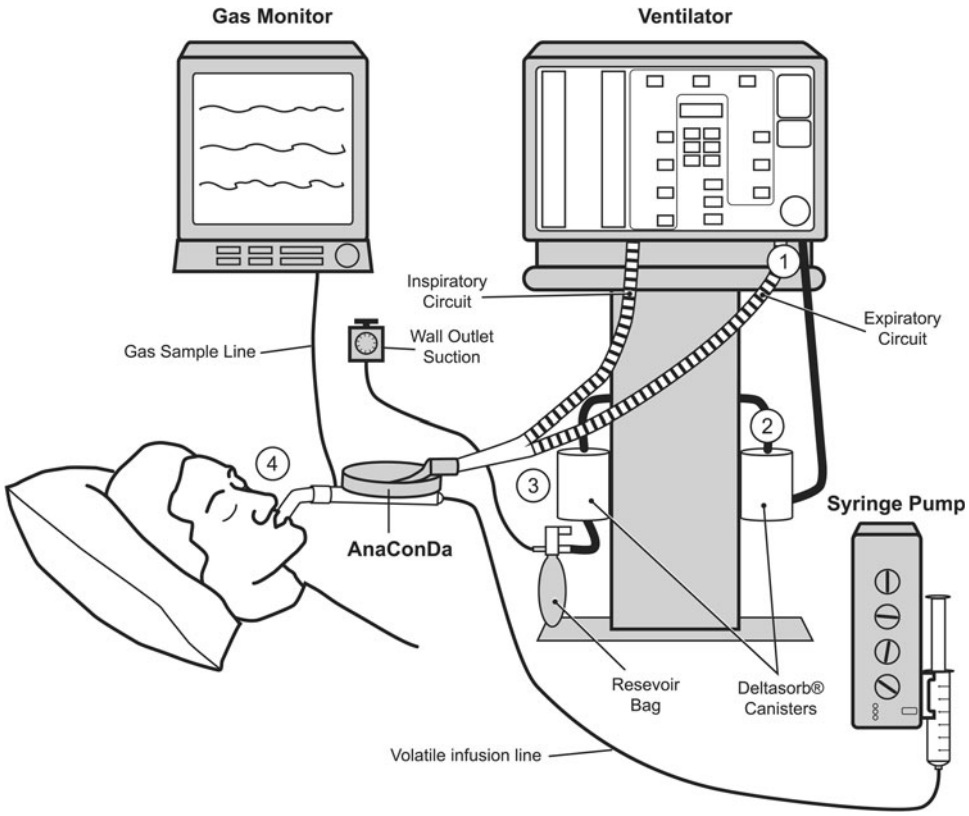

Fig. 2 Shows equipment setup, volatile agent delivery, gas monitoring, and scavenging system. Volatile gas concentrations are measured at the end-expiratory port (1), post 1st Deltasorb (2), post 2nd Deltasorb (3), and near the patient's head (4). Illustration is courtesy of J. Crossingham

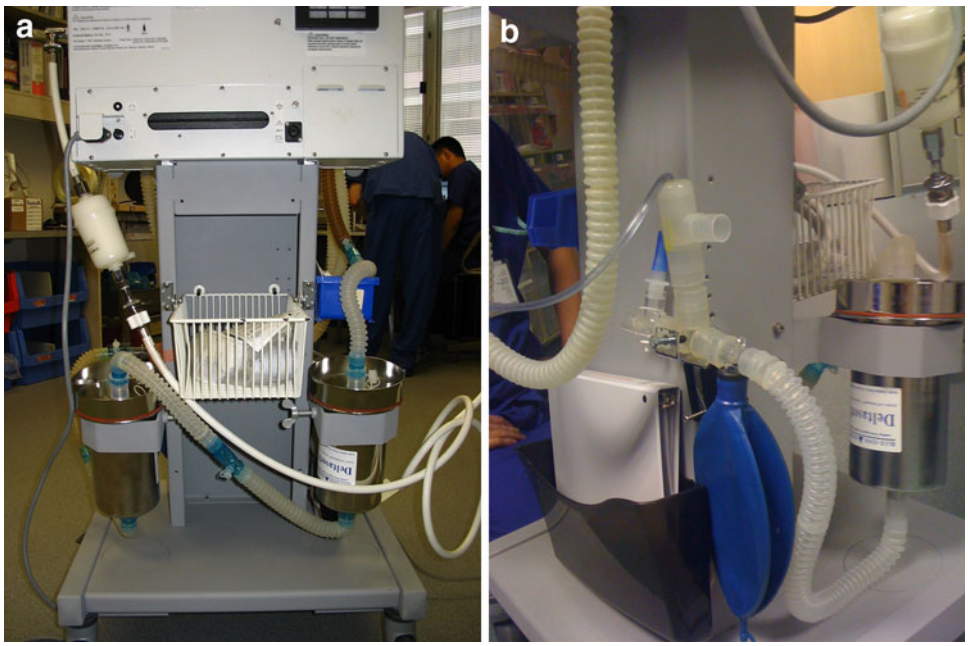

Fig. 3 (a) Scavenging system created with two Deltasorb® canisters connected in series. (b) Photograph shows a reservoir bag, which prevents the system from being overpressurized or applying an excessive vacuum

Discussion

The results of this study show that volatile anesthetics can be administered for ICU sedation with minimal contamination within critical care environments when using the AnaConDa device in conjunction with a standard ICU ventilator and the Deltasorb scavenging system developed within our institution.

The risk of adverse events with chronic exposure to volatile agents has been debated within the literature with conflicting reports. Older studies have suggested that exposure to volatile anesthetics has potential harmful effects, including a greater risk of infertility and spontaneous abortion.[15-17] More recently, a prospective trial has failed to show any association between adverse outcomes and exposure to anesthetic agents in operating rooms independent of the presence of scavenging[18,19]; however, many countries have recommended maximal allowable time exposure limits (Table 2). Our scavenging system used in conjunction with the AnaConDa device reduced the level of environmental contamination, which is acceptable to most Western countries and thus conforms to international safety standards (Table 2).[9,20,21]

The AnaConDa device has been approved for use in the European Union since 2004. Many studies have shown the AnaConDa to be a highly efficient, safe, cost effective, and simple device to use.[1,2,22] There are limited data assessing ambient room contamination, and the optimal scavenging system remains unknown. In accordance with guidance from the manufacturers of AnaConDa and the Canadian Centre for Occupational Health and Safety which governs workplace environmental exposure limits, we used a combined two Deltasorb active scavenging system in conjunction with nine room air exchanges per hour. However, in a recent case series by Marbini *et al.,* they assessed the degree of ICU environmental pollution with the AnaConDa device using isoflurane with only ten room air exchanges per hour and no additional active scavenging.[23] The authors showed peak isoflurane levels of 50 ppm at the expired port, which fell to less than 2 ppm around the patient's head and the predicted nursing area. A second study by Sackey *et al.* in 15 patients during ICU sedation for 12-96 hr looked at ambient isoflurane pollution and consumption utilizing active scavenging and four room air exchanges per hour.[2] Their scavenging system used a simpler ejector suction device that connected the ventilator to the hospital waste gas wall outlet system. Five patients within this series had no active scavenging and relied on room air exchanges alone. The mean levels of isoflurane pollution were less than 0.5 ppm in all patients. The full impact and requirement of each modality and the minimum number of air exchanges to reduce environmental contamination remain to be investigated.

There are several limitations to this study, including the small sample size and the delivered concentrations which rarely exceeded 0.1-0.3 MAC; however, the data are largely uniform with no significant outliers. Measurements were performed at one hour after ICU admission, as we anticipated this to be an adequate time period for volatile agents to reach equilibrium between the breathing circuit and the environment, and most cardiac surgical patients are also extubated within two to three hours of ICU admission. Thus, it is possible that ambient room contamination may have continued to rise beyond the one hour measurement time period. However,

Table 2 Accepted limits for occupational exposure to volatile anesthetic agents, as a time weighted average in ppm

Volatile Agent	Long term Exposure Limit (Time weighted average, 8 hr) in ppm		
	UK/Europe[20]	Canada[9]	USA[21]
Isoflurane	50	2	2
Sevoflurane	-	-	2
Halothane	10	2	2
Nitrous Oxide	100	25	25

ppm = parts per million

we tested the Deltasorb-based scavenging system within our operating rooms, which normally utilize much higher doses of volatile anesthetics (0.6-2 MAC), and the Deltasorb canister is changed only once per week. Our measurements showed that the regular ambient room concentrations never exceeded the current allowable safety limits (unpublished data). In addition to this scavenging system, there are nine room air exchanges performed each hour.

In summary, our study shows that the simple scavenging system developed within our institution together with the room air exchanges provides an efficient means to reduce ambient room contamination and staff exposure within the ICU when volatile agents are administered with the AnaConDa device. This has important safety implications with residual volatile anesthetic concentrations falling well below current guidelines and thus meeting Canadian and international safety standards. The results of this study will facilitate further research investigating potential benefits of volatile-based sedation within critical care environments.

Acknowledgements We sincerely thank the nursing staff and respiratory therapists of the Cardiovascular ICU at our institution for their support and assistance during the conduct of this study.

Disclosures This study was supported by the following grants received by Marcin Wąsowicz: Academic Medical Organization Alternative Founding Plan Phase III; Career Scientist's Award Canadian Anesthesiologists' Society; Merit Award, Dept. of Anesthesia University of Toronto.The authors have not received financial support or acted as consultants for Blue-Zone Technologies Ltd. (Concord, Ontario, Canada) or AnaConDa® (Sedana Medica, Sweden).

Competing interests None declared.

References

1. *Sackey PV*, *Martling CR*, *Granath F*, *Radell PJ*. Prolonged isoflurane sedation of intensive care unit patients with the Anesthetic Conserving Device. Crit Care Med 2004; 32: 2241-6.
2. *Sackey PV*, *Martling CR*, *Nise G*, *Radell PJ*. Ambient isoflurane pollution and isoflurane consumption during intensive care unit sedation with the Anesthetic Conserving Device. Crit Care Med 2005; 33: 585-90.
3. *Mirsattari SM*, *Sharpe MD*, *Young GB*. Treatment of refractory status epilepticus with inhalational anesthetic agents isoflurane and desflurane. Arch Neurol 2004; 61: 1254-9.
4. *Parnass SM*, *Feld JM*, *Chamberlin WH*, *Segil LJ*. Status asthmaticus treated with isoflurane and enflurane. Anesth Analg 1987; 66: 193-5.
5. *Cascino GD*. Generalized convulsive status epilepticus. Mayo Clin Proc 1996; 71: 787-92.
6. *Kong KL*, *Willatts SM*, *Prys-Roberts C*. Isoflurane compared with midazolam for sedation in the intensive care unit. BMJ 1989; 298: 1277-80.
7. *Spencer EM*, *Willatts SM*. Isoflurane for prolonged sedation in the intensive care unit; efficacy and safety. Intensive Care Med 1992; 18: 415-21.
8. *Meiser A*, *Sirtl C*, *Bellgardt M*, *et al*. Desflurane compared with propofol for postoperative sedation in the intensive care unit. Br J Anaesth 2003; 90: 273-80.
9. Ontario Ministry of Labour. Occupational Exposure Limits. Ontario regulation 833/90 amended in 2012 (149/12); Available from URL: http://www.labour.gov.on.ca/english/hs/topics/oels.php (accessed September 2012).
10. Wasowicz M, Jerath A, *Djaiani G, et al.* Expanding an anesthesiologist role beyond an operating room. Volatile based sedation in cardiac surgical patients. Br J Anesth 2012; 108 (Suppl 2): 1003 (abstract).
11. Wasowicz M, Jerath A, Djaiani G, Sharma V, Luksun W, Katznelson R. Volatile-based sedation. Where is the benefit? Crit Care Med 2011; 39: 237 (abstract).
12. *Riker RR*, *Picard JT*, *Fraser GL*. Prospective evaluation of the Sedation Agitation Scale for adult critically ill patients. Crit Care Med 1999; 27: 1325-9.
13. *Doyle DJ*, *Byrick R*, *Filipovic D*, *Cashin F*. Silica zeolite scavenging of exhaled isoflurane: a preliminary report. Can J Anesth 2002; 49: 799-804.
14. *Janchen J*, *Bruckner JB*, *Stach H*. Adsorption of desflurane from the scavenging system during high-flow and minimal-flow anaesthesia by zeolites. Eur J Anaesthesiol 1998; 15: 324-9.
15. *Rowland AS*, *Baird DD*, *Weinberg CR*, *Shore DL*, *Shy CM*, *Wilcox AJ*. Reduced fertility among women employed as dental assistants exposed to high levels of nitrous oxide. N Engl J Med 1992; 327: 993-7.
16. *Rowland AS*, *Baird DD*, *Shore DL*, *Weinberg CR*, *Savitz DA*, *Wilcox AJ*. Nitrous oxide and spontaneous abortion in female dental assistants. Am J Epidemiol 1995; 141: 531-8.
17. *Knill-Jones RP*, *Rodrigues LV*, *Moir DD*, *Spence AA*. Anaesthetic practice and pregnancy: controlled survey of women anaesthetists in the UK. Lancet 1972; 1: 1326-8.
18. *Spence AA*. Environmental pollution by inhalational anaesthetics. Br J Anaesth 1987; 59: 96-103.
19. *McGregor DG*. Occupational exposure to trace concentrations of waste anesthetic gases. Mayo Clin Proc 2000; 75: 273-7.
20. *Department of Health UK*. Health and Safety Commission. List of Approved Workplace Exposure Limits (as consolidated with amendments October 2007). Available from URL: http://www.psi.manchester.ac.uk/aboutus/healthandsafety/WorkplaceExposureLimits.pdf (accessed October 2012).
21. *NIOSH*. National Institute for Occupational Safety and Health established recommended exposure limits for the United States, 1992. Available from URL: http://www.osha.gov/dts/osta/anestheticgases/index.html (accessed October 2012).
22. *Soukup J*, *Scharff K*, *Kubosch K*, *Pohl C*, *Bomplitz M*, *Kompardt J*. State of the art: sedation concepts with volatile anesthetics in critically ill patients. J Crit Care 2009; 24: 535-44.
23. *Marbini HD*, *Palayiwa E*, *Chantler J*. Active gas scavenging is unnecessary when using the AnaConDa volatile agent delivery system. Intensive Care Soc 2009; 10: 26-8.